Appendix 9.H. Predicted changes in Vallisneria americana habitat suitability indices using modeled salinity and light conditions in the lower St. Johns River, Florida

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Introduction

During the review process, the NRC requested additional analysis be provided that considers the combined affects of salinity and light on submersed aquatic vegetation (SAV) in the Lower St. Johns River (LSJR) resulting from upstream water withdrawal. A number of alternative withdrawal scenarios have been proposed that considered various basin land-use projections. Regional hydrological and hydrodynamic models were developed to help evaluate these associated potential management alternatives. Time series output of key constituents from these models provide critical information and data useful for analyzing potential environmental effects, including possible SAV impacts. For this report (Appendix F), SAV analysis is limited to *Vallisneria americana*, because: (1) it is the dominant SAV species (Appendix B) throughout the entire spatial range where SAV can be found in the LSJR; (2) temporally, it is the most consistent SAV species (Appendix B and D); (3) historical *V. americana* monitoring data exists for analysis and comparison (Appendix G); and (4) there exist sufficient literature information regarding salinity and light limitations for *V. americana* (Appendix A) to make inferences about impacts due to water withdrawal.

To take advantage of the rich hydrodynamic and salinity model dataset, a Habitat Suitability Index (HSI) model, which can forecast *V. americana* habitat conditions, was determined appropriate for addressing the NRC suggested evaluation. A HSI model can generate a daily time series of condition values based on: affective salinity and light provided by the aforementioned models; *V. americana* salinity and light preferences discussed previously in this report (Appendix A); and scaling factors from literature information that can convert salinity and light values to relative plant condition indices. In addition, a similar stressor response model was developed for the Caloosahatchee Estuary (Mazzotti 2008) that can serve as a guide for addressing this report's objective.

The objective of this report is to develop a HSI model at fixed stations to assess potential impacts from proposed water withdrawal that considers temporal influences from the combined affects of salinity and light. To achieve this objective, the HSI model will generate daily Relative Condition Index (RCI) values for *V. americana* based only on salinity and light suitability. Because the RCI output depends only on salinity and light influence, the RCI is not expected to closely track *V. americana* density or other response measurements of actual plants made during field monitoring. There are many other factors beyond the modeling scope of this effort that can dramatically influence *V. americana*

Methods

Preliminary results from Phase I analysis indicate that significant potential effects to SAV due to changes in salinity are unlikely outside the area between the Fuller-Warren Bridge (Figure 1: River Mile 25; River Kilometer 40) and the Shands Bridge (R.M. 50; R.K. 80). Three fixed stations (Bolles School, Buckman Bridge, and Moccasin Slough) were selected within this area (Figure 1) for HSI development based on their longitudinal position in the river, their differing potential for salinity-light effects, and the possible range of different stress levels on the plants because of water withdrawals.

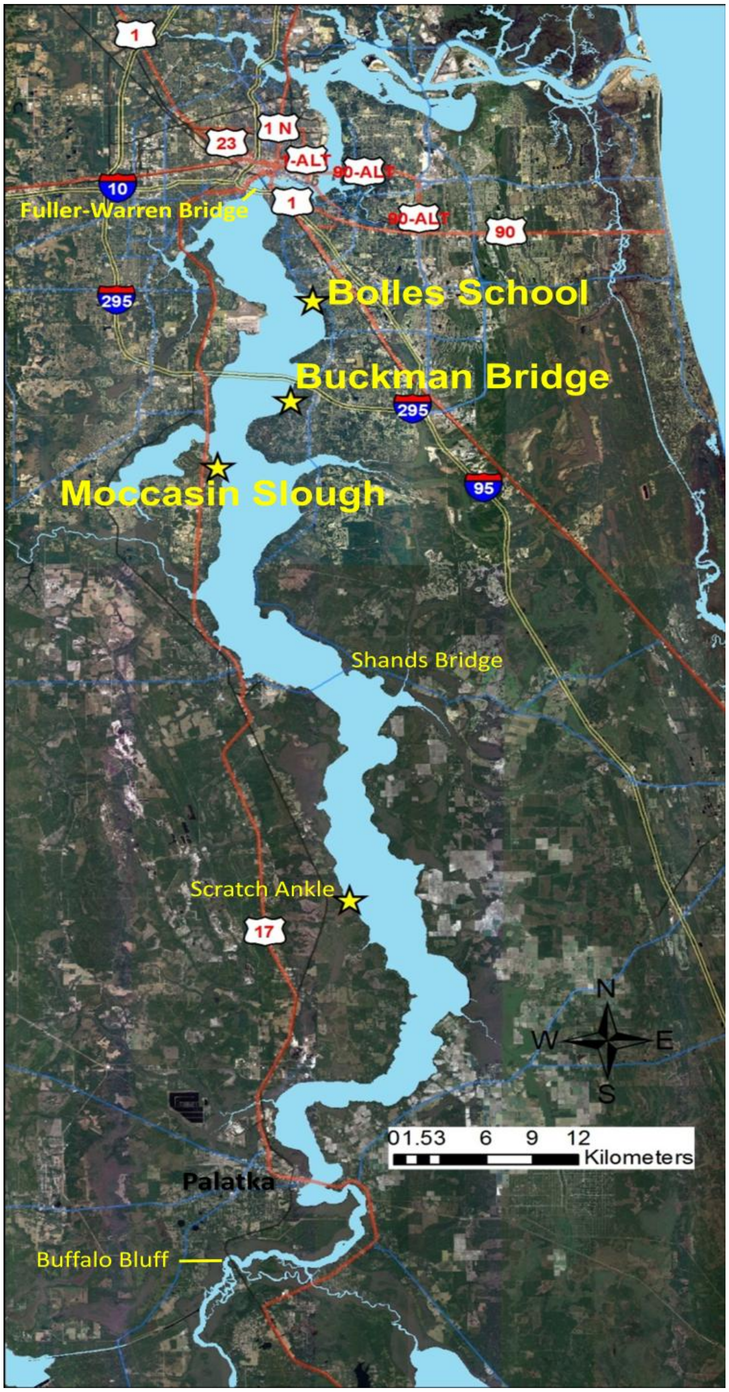

Figure 1. Location of three (3) fixed stations (Bolles School, Buckman Bridge, and Moccasin Slough) within the critical river section (Fuller-Warren Bridge to Shands Bridge) analyzed for *V. americana* effects due to proposed water withdrawals.

The development of the HSI model, with a daily reporting value, required daily salinity and light information, as well as support processes to develop a the Relative Condition Index (RCI). Figure 2 provides a flow chart that identifies the processes and where they intervene to support the primary salinity and light pathways that lead to generating daily RCI.

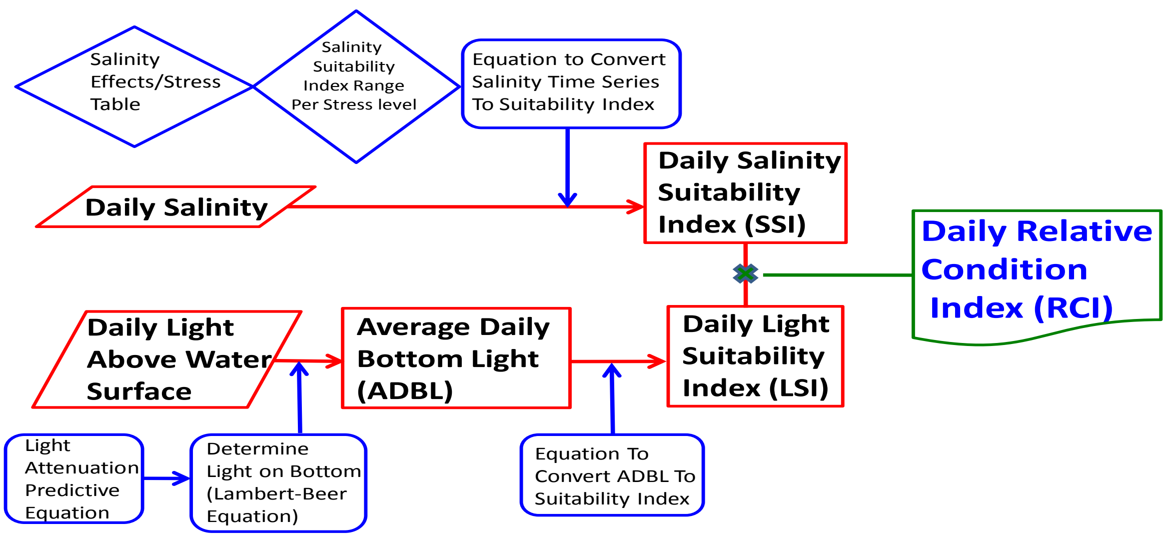

Figure 2. Flow chart depicting the HSI model development, indicating the primary salinity and light pathways, culminating in the development of the daily *V. americana* Relative Condition Index. Intervening support processes also are displayed at the top and bottom of the chart.

SALINITY

Daily salinity data (PSU: practical salinity units) is provided by the hydrodynamic/salinity model output for each fixed location during the period of record, 1995-2005. The expected response of *V. americana* to various salinity concentrations and duration of exposure (referred to in top left of flow chart) is based on the color-coded table provided by Moore (Table 1) in Appendix A. Within Table 1, the levels of stress are associated with the range of colors from green to red, indicating that as salinity and duration of plant exposure increases, the stress level increases from plants being in good condition with negligible stress (green) to extreme and critical stress conditions (red) that may lead to plant mortality. A scale from 0.0 to 1.0 was then assigned to represent a quantitative range relative to expected *V. americana* condition associated with each stress level (Table 1 Legend: Salinity Suitability Index range). This assigned quantitative scale is referenced by the second diamond in the flow chart.

Vallisneria americana

Salinity	Time - Days of salinity exposure: 1	7	30	90
25	0.05	0.01	0.00	0.00
15	0.44	0.42	0.33	0.09
10	0.70	0.68	0.59	0.35
5	0.96	0.94	0.85	0.61
3	1.00	1.00	0.95	0.71

Legend:

*** Stress level color code and naming designation**

*** Salinity Suitability Index (SSI) range of values corresponding to stress level**

G	No Effects - Good Condition (1.0 - 0.70)
S	Stressed (0.70 - 0.40)
ES	Extreme stress (0.40 - 0.10)
CS	Critical Stress (0.10 - 0.0)

Table 1. *Vallisneria americana* stress levels related to salinity (psu) and duration of exposure. The Legend includes the range of Salinity Suitability Index values assigned to each stress level. The main table includes corresponding salinity suitability index values for each cell calculated from a multiple regression *Equation A*, with salinity concentration and exposure duration as independent variables.

The third processing requirement involved developing an equation, which represents the stress levels and associated suitability index range in Table 1. In order to convert the time series of daily salinity values (from the hydrodynamic/salinity model) to daily Salinity Suitability Index values (SSI) a suite of multiple regression equations were evaluated. The selected regression equation is depicted below (*Equation A*). It was developed by building a data matrix of two independent variables that included the duration of exposure from 1 day to 90 days repeated for each salinity unit from 0.0 to 25.0. The corresponding dependent values of SSI were matched to each combination of salinity *vs* duration of exposure. These dependent values for SSI were assigned based on the expected range that was considered appropriated for the stress level (as indicted in the Legend of Table 1).

Equation A

$$SSI = a - (b * s) - (c * d)$$

Where: **s** = salinity (psu), and **d** = number of days (duration of exposure);
a, **b**, and **c** are the estimated regression coefficients, such that
a = 1.22285, **b** = 0.0516748, and **c** = 0.0019 if **s** < 0.6 or **c** = 0.00395662 if **s** $\geq$ 0.6;
Two Limiting Criteria: if SSI < 0, then SSI = 0.0, and if SSI > 1.0, then SSI = 1.0

Table 1 also displays the SSI values within the main table resulting from applying *Equation A* to each of the corresponding table's salinity *vs* duration cell matches. The cell values in Table 1 correlate well with the stress level ranges in the Legend and therefore are considered verification that *Equation A* adequately predicts *V. americana* condition due to salinity stress.

To determine the daily SSI value at each fixed station, *Equation A* was applied to each day's salinity values provided by the hydrodynamic/salinity model (where **d** = 1 in *Equation A*). The equation also was applied to the 7-day running average salinity, 30-day average, and 90-day average. Therefore, on each day, a SSI value was generated for the "day of" and 7 days, 30 days, and 90 days of exposure. The duration of exposure with the lowest SSI value for each day was selected to represent that day's SSI.

LIGHT

Daily Average Light (microEinsteins m^{-2} of Photosynthetically Active Radiation) above the water surface was calculated from daily light data provided by the modeling group (Figure 3). The daily values represent area wide available solar radiation and therefore are the same for each fixed station.

Two initial processes were required to move along the light pathway from the daily light data at the water surface to calculate the Average Daily Bottom Light (ADBL) that is available to plants. These two process are identified at the bottom left of the flow chart. First, the daily light attenuation at each station must be estimated, which can then be used in the Lambert-Beer equation (*Equation B*) to determine the available light at specified depths. The Lambert –Beer equation is as follows:

Equation B

$$I_z = I_0 * (e^{-K(Z)})$$

Where: $\mathbf{I_z}$ = submerged light intensity (PAR) at **Z** meter depth; $\mathbf{I_0}$ = the light intensity just below the water surface; and **K** = the attenuation coefficient.

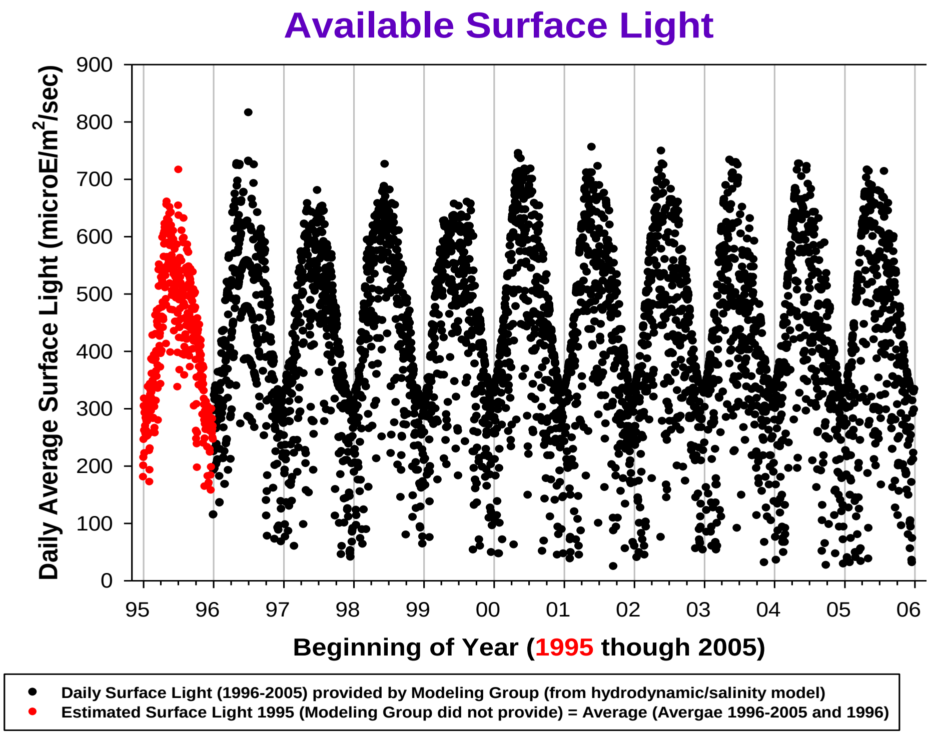

Figure 3. Daily average light (photosynthetically active radiation) above the water surface (considered applicable at all three fixed stations).

Daily water column light attenuation (**K**) for each fixed station was determined by using a multi-layered regression approach. At each fixed station, 3 separate nonlinear regression equations were developed using field derived attenuation at each station (dependent variable), verses the independent variables of: (1) same day salinity; (2) day of the year; and (3) the freshwater flow volume at Buffalo Bluff (Figure 1: 90 R.M., 145 R.K.). These three separate equations were used as independent variables in development of a 3- factor multiple regression equation to predict daily light attenuation at each station. The 90% value of daily surface light was calculated to represent incident light (just below the water's surface) and used along with the newly estimated daily **K** value as input for the Lambert-Beer equation to determine the average daily bottom light for 0.1m depth intervals from 0.1 m to 1.0 m. These individual depth-specific values were combined to estimate the ADBL for the depth range of 0.1-1.0 m.

To progress from ADBL to estimating the daily Light Suitability Index (LSI) value (see Figure 2 Flow Chart), the relationship between ADBL and light suitability must be determined. A number of researchers have considered ADBL requirements of *V. americana*, including Harley and Findlay (1994), Hunt (2003), Hunt et al. (2003, 2004), and Hunt and Doering (2005). Adopted for this report, Mazzotti et al. (2008) developed a LSI scale that considered both literature information and unpublished experiment results (Figure 4). As with the SSI, the LSI scale also extends from 0.0 to 1.0. It is based on ADBL relative affects on *V. americana* at two levels of salinity (when salinity is < 9.5 and ≥ 9.5psu). One of the non-linear regression equations that describe these two curves was applied to estimate daily LSI. The equation that was selected depended on the daily salinity value provided by the hydrodynamic/salinity model.

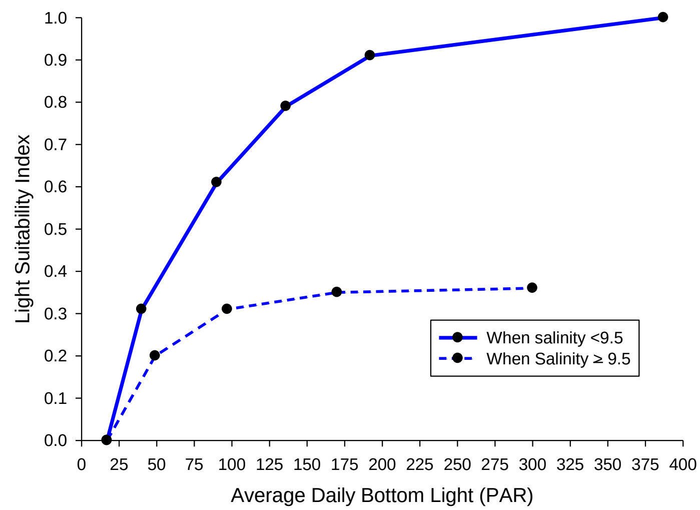

Figure 4. *Vallisneria americana* daily average bottom light (PAR, µE m^{-2}) vs. light suitability index values. For this analysis, a clean demarcation between two curves was used, however, actually a sliding scale probably exists (of unknown proportions), whereby as salinity increases toward 9.5, the solid line tends toward the dotted line.

RELATIVE CONDITION INDEX

Once the daily SSI and LSI values were estimated, the final step in the flow chart (to generate the daily Relative Condition Index values) was achieved by multiplying the SSI and LSI daily values. At each station, a percentile curve of daily RCI values was developed for the BASE condition and FULL withdrawal scenarios to compare the differences in the shapes of the curves and changes in the frequency of the stress levels associated with the two flow scenarios.

Even though only salinity and light factors were considered in the HSI model, the time series pattern of RCI values were compared with *V. americana* abundance data, which consisted of qualitative *V. americana* density (no plants, sparse, moderate, and dense) reported during routine transect monitoring at the three stations during 2001 though 2005. There are multiple transects per station aligned perpendicular to shore. The qualitative *V. americana* estimates and their associated water depth are reported every 1.0 m along the transect. These qualitative designations were respectively assigned relative density values of 0.0, 0.2, 0.5, and 0.8 to maintain the same scale determined above for the SSI, LSI and ultimately the RCI. For comparison, the average relative density at the 0.05 - .94 m depth was calculated for each field day and plotted against the daily RCI for the 0.1 to 1.0 m depth range.

Results

SALINITY SUITABILITY INDEX

Salinity time series plots were generated (Figure 5) for the period of record (1995 – 2005) at Buckman Bridge for both the BASE condition and FULL withdrawal scenario (with no future projects) that includes flows from Ocklawaha. Time series graphs were also generated at Bolles School and Moccasin Slough that depicted similar comparisons. The difference in salinity concentrations between the two scenarios (regardless of the location) was so small that these two scenarios became the focus for analysis, because if significant difference could not be discerned, then there was no need to analyze other scenarios with less impacts.

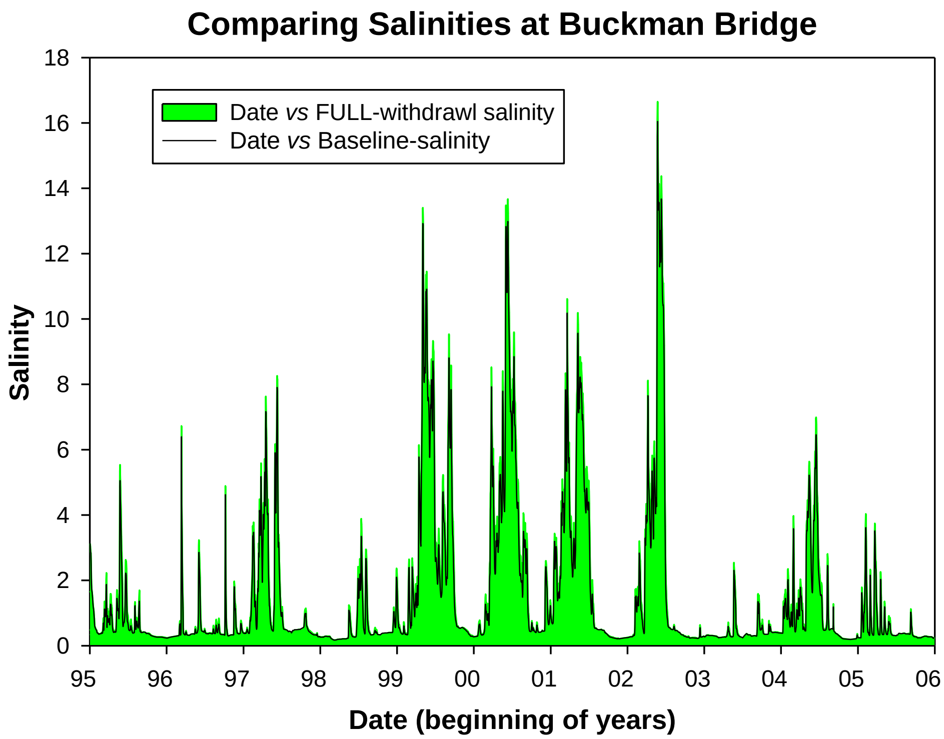

Figure 5. Salinity time series of model output at Buckman Bridge for the BASE condition and the FULL withdrawal (with no future upstream projects and including flows from Ocklawaha).

The SSI *Equation A* was applied to the salinity output for each station (Figure 6). As with the time series plots of salinity concentration, the resulting SSI curves for the two scenarios displayed little differences.

<u>*LIGHT SUITABILITY INDEX*</u>

Even though surface light was provided by the modeling group, there remained the need to estimate light attenuation in order to determine available bottom light (Figure 2 Flow Chart). At each of the three fixed stations, light attenuation is routinely determined by applying a light model produced by Gallegos that uses water quality monitoring data as independent variables. This pseudo field-determined light attenuation coefficient (**K**) was used as the depended variable (with a Log_{10} transformation) in constructing non-linear regression equations that compared the field-derived **K** to: (1) flow volume; (2) day of the year; and (3) salinity. Both flow and salinity are influential in controlling water quality constituents that affect light transparency, while solar radiation varies throughout the year depending largely on seasonal changes related to sun angle,

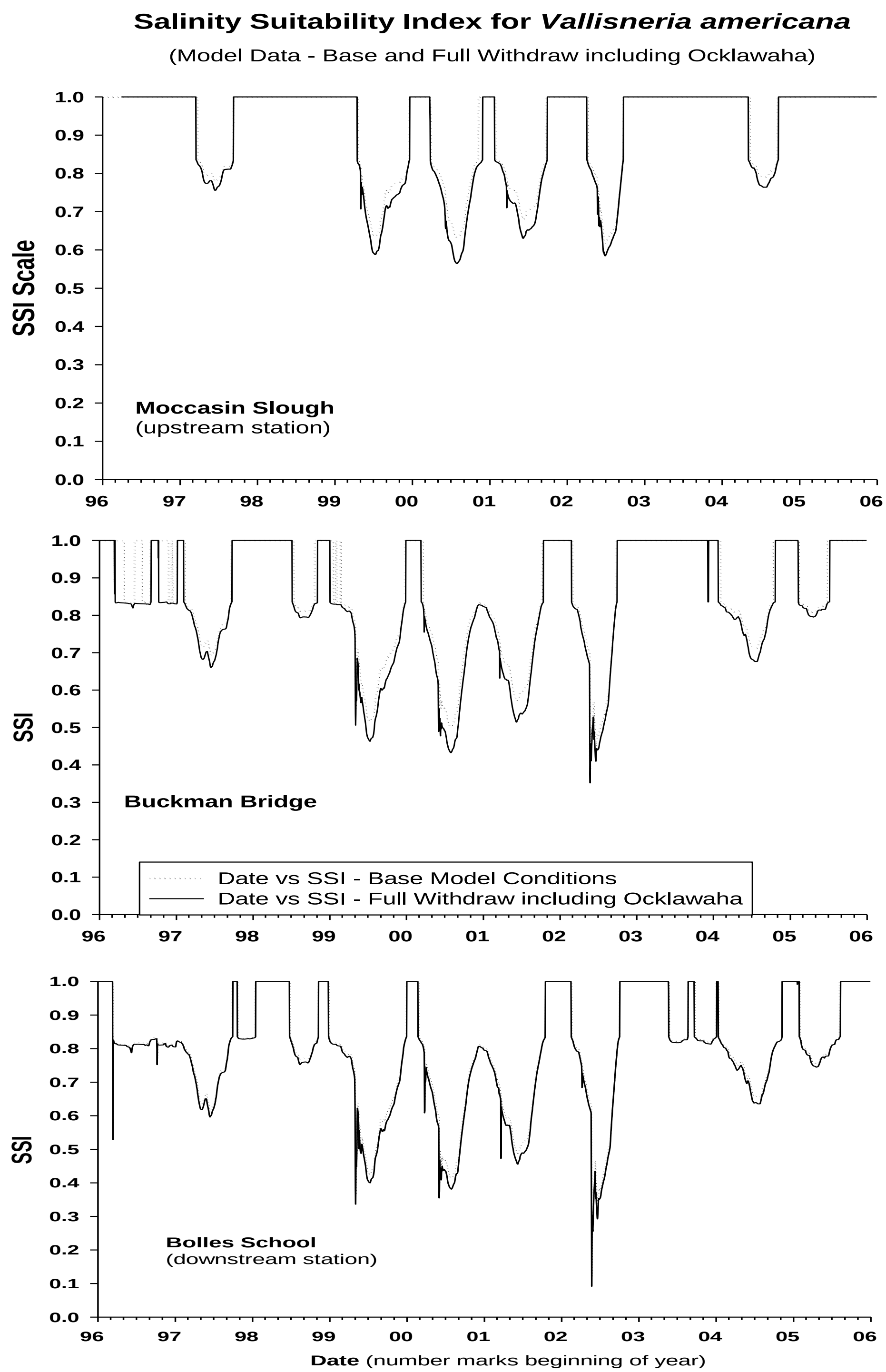

Figure 6. Salinity Suitability Index (SSI) curves for the BASE and FULL Withdrawal scenarios at the three stations.

day length, and solar intensity. The flow and salinity data used in the regressions were supplied by hydrologic and hydrodynamic/salinity model output for the BASE condition. The regression results for the Buckman Bridge site are depicted in Figure 7. The remaining stations' regression curves were similar. At Buckman Bridge, the combined multiple regression equation (Equation 4 in Figure 7, that used the non-linear regression equations as independent variables) resulted in an adjusted coefficient of determination of 66% (Figure 7). The R^2 at Moccasin Slough and Bolles School was 56% and 63%, respectively. The same multiple regression equation for each station also was used to determine the light attenuation during the FULL withdrawal scenario, such that the flow and salinity data associated with the FULL withdrawal were used in Figure 7's Equations 2 and 3 for deriving **K** from Equation 4.

Buckman Bridge: Predicted Light Attenuation (K) Based on Field-derived K, Day of Yr, Model (Base) Salinity, and Flow

Equation 4…Combined Regression:

$\log_{10}(Kd) = (-.100714)$
$+.329747 * (\textbf{Eq}1\ldots\textit{Day of Year})$
$+.428844 * (\textbf{Eq}2\ldots\textit{salinity})$
$+.554309 * (\textbf{Eq}3\ldots\textit{flow})$

Adj. $R^2 = .66$

Figure 7. Nonlinear regressions and equations relating Log_{10} transformed $\mathbf{K_d}$ (from Gallegos model) *vs* "day-of-the-year", salinity (from model output for BASE conditions), and flow volume. The resulting reported formulas served as the independent variables for the combined regression (*Equation 4* within the figure).

A time series plot of the field-derived **k** values and the predicted **k** (untransformed) from the combined multiple regression is depicted in Figure 8 for the Buckman Bridge site under the BASE condition. The same plots generated at the other two sites (not shown) depicted similar agreement between observed and predicted values regarding daily and seasonal patterns.

The light attenuation coefficient (**K**) determined above, along with the estimated $\mathbf{I_0}$ (90% of daily light available at the surface) were used as input to the Lambert-Beer *Equation B* to determine the average daily bottom light for the range of depths of 0.1-1.0 m. This daily value was fed into the curvilinear regressions that represent the relationship between the ADBL and the daily LSI (Figure 4). The resulting daily LSI widely varies from day to day due to water and sky conditions. The daily LSI depicted in Figure 9 for the Buckman Bridge BASE condition typifies the LSI time series pattern for all three stations. The processes (depicted in Figure 2 Flow Chart) were repeated for the FULL withdrawal scenario at each station.

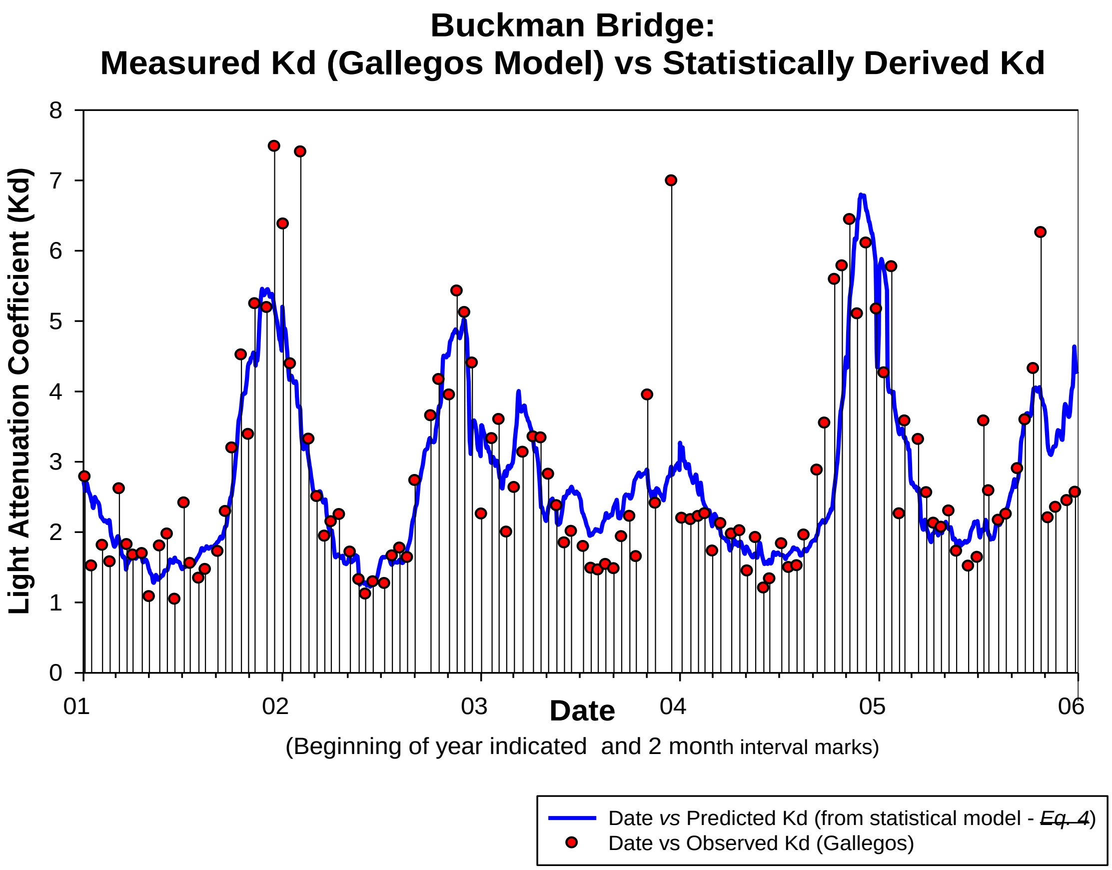

Figure 8. Time series of field measured $\mathbf{K_d}$ (field-derived from Gallegos model) and daily predicted $\mathbf{K_d}$ from applying Equation 4 (linear multiple regression model) reported in Figure 7.

RELATIVE CONDITION INDEX

The daily reference condition (RCI) was determined by multiplying the SSI and LSI daily values. To facilitate comparison with *V. americana* field measurements, the daily RCI at the 0.1 – 1.0 m depth range was plotted with a time series of *V. americana* relative densities. The plot for Buckman Bridge is depicted in Figure 10. The relative *V. americana* density in the graph represents the average of all density values on the sampling day within the same depth range of 0.05-0.94 m for all transects combined.

The results depicted in Figure 10 at Buckman Bridge indicate that the RCI is generally within the same range as the relative density scale chosen to represent the qualitative plant data. Both the RCI and the relative plant density patterns at Moccasin Slough and Bolles Schools are very similar to Buckman Bridge, with actual values of both slightly less at Bolles School and slightly greater at Moccasin Slough.

The RCI values generally remained below the good range (RCI >0.7, Figure 2), except during 2003 and 2005. The average *V. americana* conditions of field-measured plants was always in a state of stress (*V. americana* relative density < 0.7). The RCI also appears to overestimate plant condition, which is probably largely due to a strong lag response that is most noticeable during the January – September 2002 period when plant density was at the critical stress level and did not recover despite conducive salinity and light conditions. Since the RCI considers only salinity and light, then the RCI tendency to overestimate is expected.

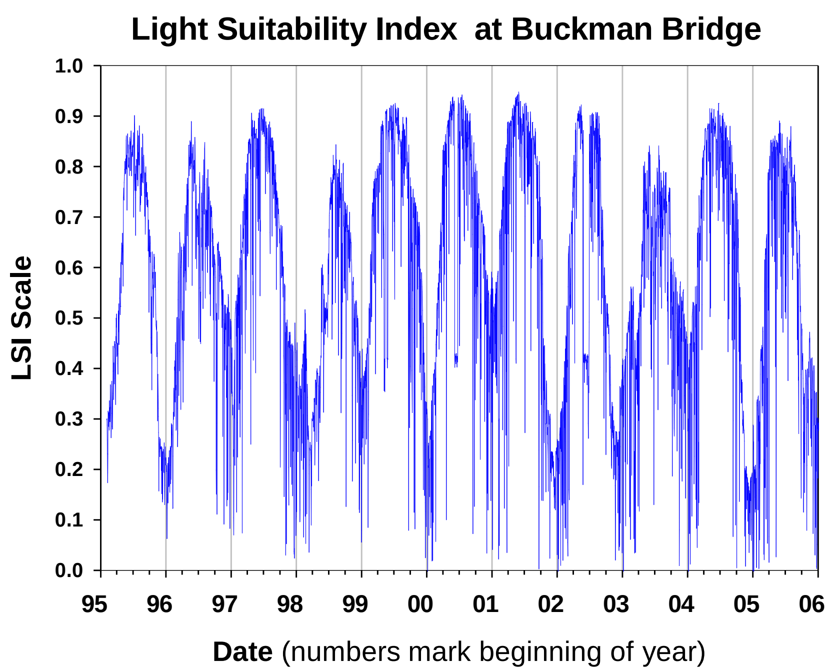

Figure 9. Daily Light Suitability Index (LSI) at Buckman Bridge.

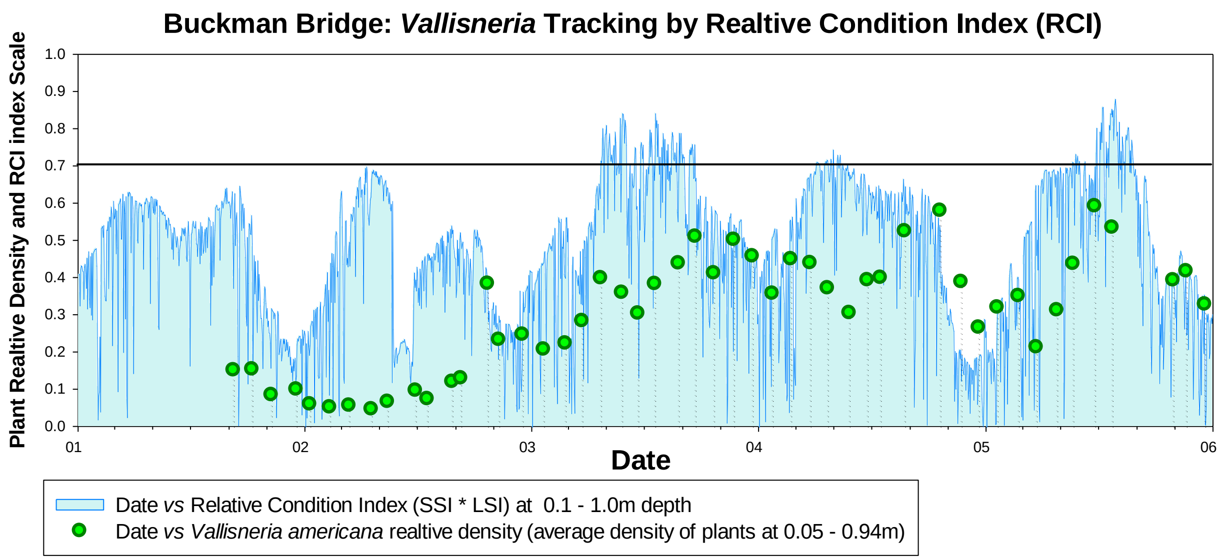

Figure 10. Time series of average *Vallisneria americana* relative density and the Relative Condition Index. RCI values and relative plant density > 0.7 (line) are in the good condition range.

The analysis results thus far indicate there is reasonable agreement between predicted values and field data (for salinity, light attenuation, and relative *V. americana* density). Therefore, when the HSI methodology for analysis is consistently applied, the RCI output does serve as a useful tool for evaluating the combined affects of salinity and light related to water withdrawal.

COMPARISON OF WATER WITHDRAWAL SCENARIOS

Graphs of RCI percentile values *vs* the RCI scale are provided for each site to help assess differences between the BASE and FULL withdrawal conditions (Figure 11). Each of the graphs indicate the percentile (percentage of the daily RCI values on the y-axis) that are less than or equal to a specific RCI value (on the x-axis). For example, at Buckman Bridge, 50% of the RCI values (0.50 on the y-axis) are less than a RCI of about 0.50. The median RCI value during the period of record is equivalent to the 0.50 percentile for all graph lines. The other way to view the same results is 50% of the daily RCI values are greater than 0.50, which includes the RCI values from about 0.50.

At the RCI value of < 0.4, which is depicted on each site's plot (Figure 11), the plants are expected to start experiencing extreme stress. For example, at Buckman Bridge, about 30% of the daily BASE RCI values are <0.4. Included in the graphs are references lines on both sides of the BASE condition line that represent ± .05 and ± 5% of the RCI value that corresponds to the RCI percentile value. In all cases, the FULL withdrawal condition is within 0.05 RCI units of the BASE condition and are very close to, or less than 5% of the BASE condition.

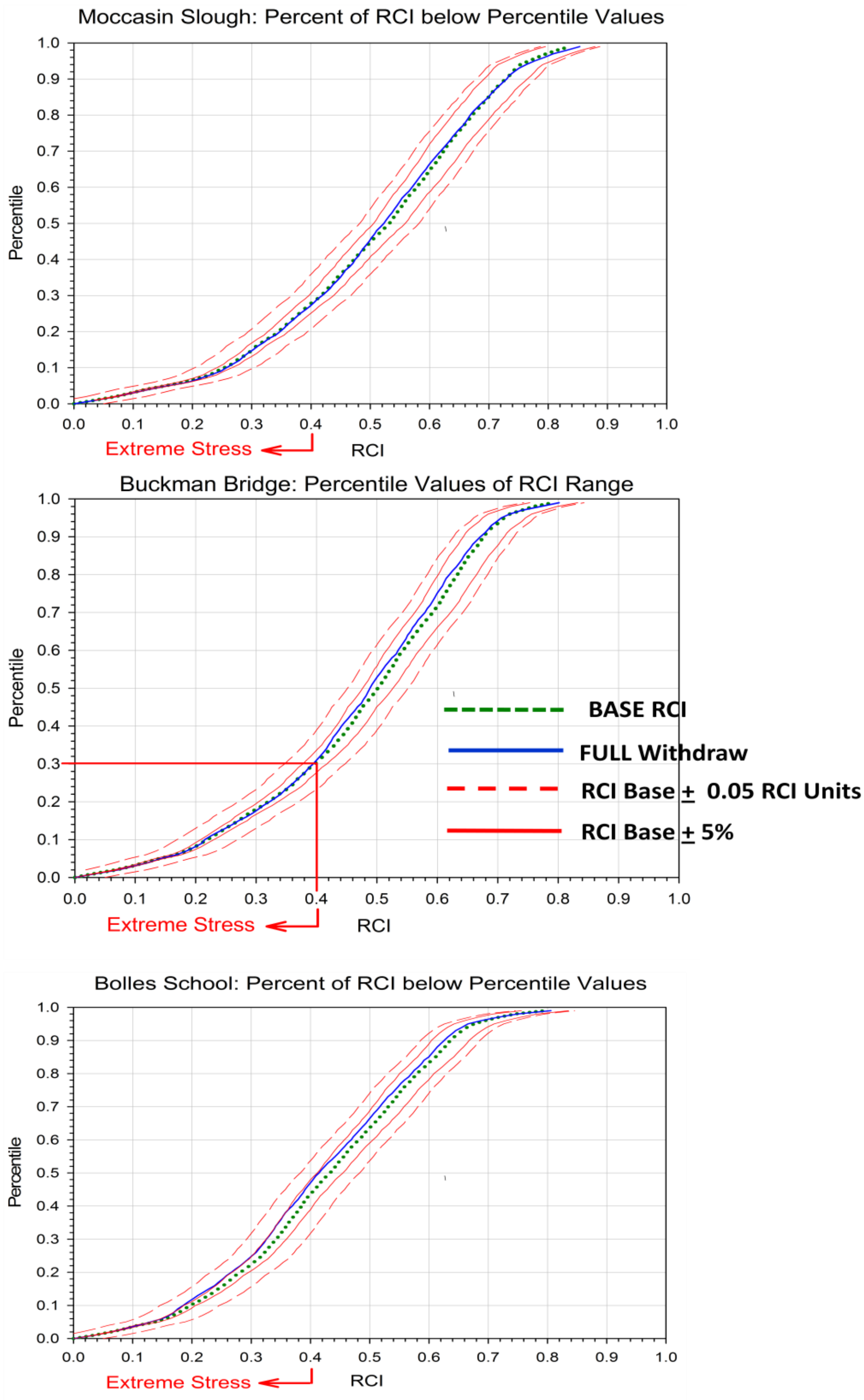

Figure 11. Percentile values for the daily RCI values at the three analysis sites. The curves represent the frequency of occurrence of each RCI value for the BASE and FULL withdrawal conditions (with the Ocklawaha). Reference lines also are provided indicating ± 0.05 RCI units from the BASE condition RCI value, as well as ± 5% of the BASE condition.

The lines representing the BASE and FULL withdrawal condition in Figure 11 are very close and sometimes intertwine, indicating decreases in the percentile within certain RCI range increments and subsequent decreases in another range. Table 2 also depicts these changes in the percentile values from the BASE to the FULL withdrawal condition (last column in Table 2). Regardless of the site location, the percent of RCI values greater than 0.7 (plants in good condition or not affected) declined slightly (<1.0%) and the percentage of RCI values less than 0.7 (plants affected) increased by the same amount at their respective locations. At Moccasin Slough the expected increase in affected plants was in the RCI stress range of <0.7 -0.4, while the percentage of *V. americana* plants in the extremely stressed and critical stressed range declined. The biggest increase in affected plants associated with the FULL withdrawal scenario occurred at Buckman Bridge (0.54%), where all the increase occurred in the extreme stress range (<0.4), with contributing increases in the critical stress range (RCI <0.1). At Bolles School, even though there was only a small increase in affected plants (0.20%), there was a >3.0% increase in extremely stressed *V. americana* plants that were previously in the less stressed range of <0.7 – 0.4. Again, it should be noted that, except at Bolles School, all the changes were less than 1.0%.

Conclusions

Based on the results reported above concerning the impacts from the FULL withdrawal, the amount of increased stress to *V. americana* within the section of river evaluated is predicted to be small when considering only the combined effects of light and salinity. As mentioned in the introduction, there remain other important factors that are unaccounted for in the HSI model, the biggest probably being plant buffering capacity against short term declines in water and light conditions, as well as the increased recovery time required by *V. americana* after prolonged exposure to poor conditions.

Another major concern, regarding future influence on SAV status, is the unknown effects that could result from adding the stress of other factors, that when combined with the water supply withdrawals, could increase adverse impacts past the population's assimilation capacity. Some other possible factors that could affect *V. americana* include: (1) changes in downstream river configuration that increases saline water conveyance to upstream areas (e.g., downstream channel and port dredging); (2) declines in water clarity due to increased phytoplankton or nutrient enhancement of epiphytes; (3) increase in water depth from sea level rise with no landward area available for SAV to migrate upslope; and (4) potential harmful storms that severely damage beds byond their ability to recover under prevailing stressed conditions.

Table 2. The greatest RCI value, the percent of RCI values within identified important RCI ranges, and the amount of change between the BASE and FULL withdrawal condition at each of the three analysis sites. At all three locations, the lowest RCI value was 0.0 under both scenarios, which consistently accounted for 0.11% of the daily RCI values.

	Location	BASE,NN Condition	FULL Withdrawal Condition (with the Ocklawaha)	Change from BASE to FULL
Greatest RCI Value	Moccasin Slough	.93	.91	-0.02
	Buckman Bridge	.88	.89	+0.01
	Bolles School	.89	.87	-0.02
%RCI > 0.7 (Good Condition)	Moccasin Slough	15.03%	14.99%	-0.04%
	Buckman Bridge	6.38%	5.84%	-0.54%
	Bolles School	3.76%	3.56%	-0.20%
%RCI < 0.7 (Plants Affected)	Moccasin Slough	84.96%	85.00%	+0.04%
	Buckman Bridge	93.61%	94.15%	+0.54%
	Bolles School	96.23%	96.43%	+0.20%
%RCI <0.7 to 0.4 (Plants Stressed)	Moccasin Slough	57.21%	57.77%	+0.56%
	Buckman Bridge	63.31%	63.28%	-0.03%
	Bolles School	52.59%	49.58%	**-3.01%**
%RCI < 0.4 (Extreme Stress)	Moccasin Slough	27.74%	27.22%	-0.52%
	Buckman Bridge	30.29%	30.86%	+0.57%
	Bolles School	43.63%	46.84%	**+3.21%**
%RCI < 0.1 Critical Stress	Moccasin Slough	3.14%	2.96%	-0.18%
	Buckman Bridge	3.22%	3.04%	+0.18%
	Bolles School	3.62%	3.62%	0.0%

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